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Title: Multiphase Flow Calculations in CartaBlanca

Author(s): Zhang, Duan Zhong

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# Multiphase Flow Calculations in CartaBlanca

Duan Z. Zhang

Fluid Dynamics and Solid Mechanics Group
T-3, Theoretical Division
Los Alamos National Laboratory
Los Alamos, New Mexico, USA

# What is CartaBlanca

CartaBlanca is a multi-material and multi-physics code.

- Based on the advanced multi-material interaction theory.
- Uses unstructured mesh (for complex geometries).
- Written in Java, taking advantage of object-oriented Java structure.
- Easy to add user modules. (Developer friendly).

**Traditional fluid dynamics:**

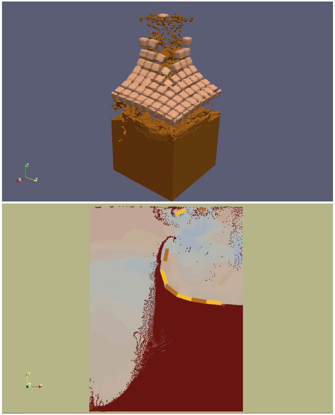
- Reacting multiphase flows. Fluidized bed.
- Heat and mass transfer for nuclear reactors.
- Nuclear fuel separation in centrifugal contactors.
- Multiphase flows and reactions in porous material.

**Advanced multi-material interactions:**

- Fluid-structure interactions.
- Hypervelocity impact in air or under water.
- Material pulverization and solidification.
- Structure dynamics (e.g. Blast loading).

# A Brief History of CartaBlanca

- Started as a small project about 20 years ago with the goal to build a test bed for new material models and new numerical algorithms.
- R&D 100 award, 2005.
- Used in many projects by universities and companies:
  - Penn State, MIT, Columbia, U. Taxes, ...
  - BP, Chevron.
  - Acta Inc. (A DoD contractor)
    - Massively parallel implementation
    - K & C Concrete model
    - ParaView post processing

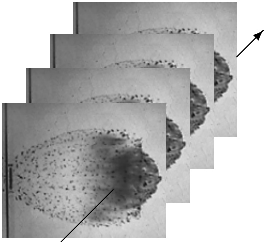


Courtesy of Acta Inc. Torrance, CA

# Ensemble Phase Averaging Method

Multiphase flows are stochastic and multiscale. Common theories are based on volume averaging method.

- What is the size of the representative volume element (RVE)? Does such a size exist?



$(x, t)$

**Ensemble Phase Average**: Average over many experiments.

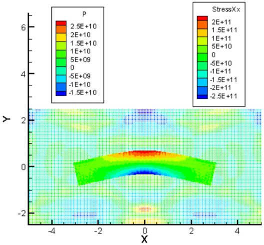
$$\text{Vol. frac.}(x, t) = \frac{\#\text{ of times } (x, t) \text{ in the phase}}{\#\text{ of exps.}}$$

$$\text{Avg. vel. of a phase } (x, t) = \frac{\text{sum of vel's when } (x, t) \text{ in the phase}}{\#\text{ of times } (x, t) \text{ in the phase}}$$

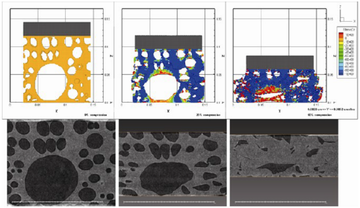
- No need for RVE.
- More directly related to physics at lower length and time scales. Less human interpretation of physics.

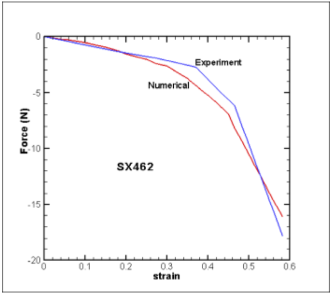
# Multi-velocity Formulation

- Each material can have its own velocity, stress, and internal energy fields.
- Material interactions are considered through interaction forces in the equations not through the material interfaces.
- Applicable in cases of “body interactions”.



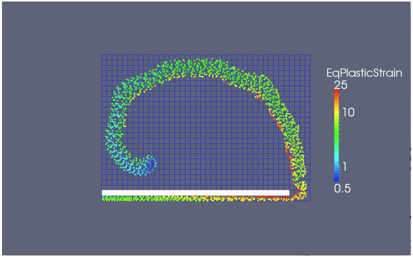

Dual domain material point method (DDMP) for complex geometry:

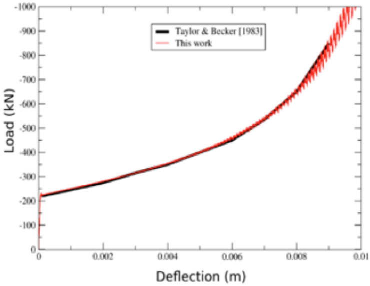


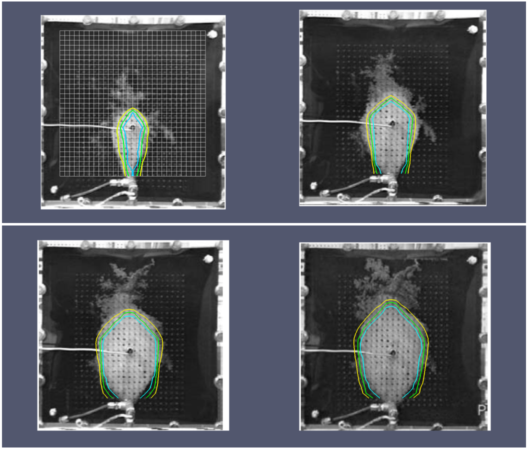


# DDMP for Extreme Deformation

- Particle-in-cell (PIC) method invented by Frank Harlow in the 1960s.
- In the late 1980s, shape functions were introduced (FLIP).
- In the 1990s, reformulated using virtual work theory (MPM).
- Improved with noise reduction technique (DDMP) (2011).
- Applicable for history dependent problems with large deformation. It has very little numerical diffusion.





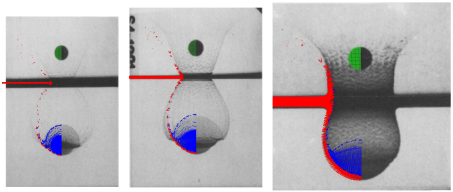
Formation of steam chamber

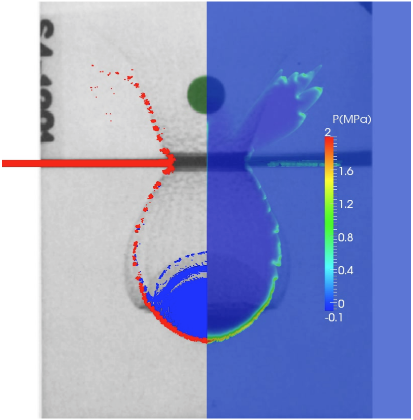
**Steam assisted gravity drainage (SAGD)**

- Steam injection from the top well.
- Steam turns into water releasing latent heat on the wall of steam chamber.
- Oil temperature increases, and viscosity reduces.
- Oil drains to the bottom well under gravity.

# Material Pulverization

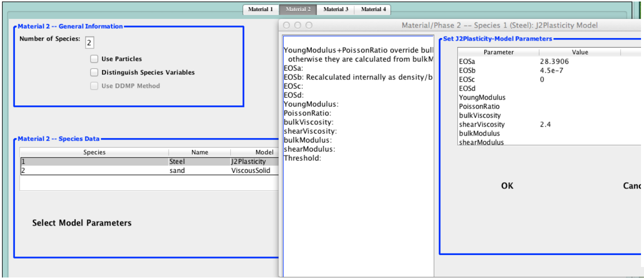
- An aluminum ball impacts on aluminum plates of various thicknesses. V = 6.7 km/s.
- Red particles are calculated plate material.
- Blue particles are calculated ball material.





# Input and Output

- Currently, upto 4 materials (4 separate velocity fields).
- Each material can contain many species.
- Each species can have an independent material model.
- Many material model selections from the pull-down menu.




- Easy to add new one. (Developer friendly code.)

# Future Work

We are interested in understanding new physics.

- Not a commercial code.
  - We will work closely with interested users.
  - Work with 1-3 users on a project.
- We focus on physical problems.
  - We will develop physical models together.
  - Our partners are **not** paying for code development.
  - They pay for capability development.
- We can design user interface together.
  - No one will need all of these capabilities.
  - Design a user interface for a category of problems.
  - Need user participation and feedback.